(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
25 January 2001 (25.01.2001)

PCT

CN 1361873A

(10) International Publication Number
WO 01/06286 A1

(51) International Patent Classification[7]: G02B 6/12

(21) International Application Number: PCT/GB00/02703

(22) International Filing Date: 14 July 2000 (14.07.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
9916642.3 15 July 1999 (15.07.1999) GB

(71) Applicant *(for all designated States except US)*: **UNIVERSITY OF BRISTOL** [GB/GB]; Senate House, Tyndall Avenue, Bristol BS8 1TR (GB).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **WHITE, Ian, Hugh** [GB/GB]; 57 Coombe Park, Weston, Bath BA1 3NH (GB). **PENTY, Richard, Vincent** [GB/GB]; 55 Redland Road, Bristol BS6 6AG (GB). **YU, Siyuan** [CN/GB]; 33 Druids Woods, Stoke Bishop, Bristol BS9 1SZ (GB).

(74) Agent: **VIGARS, Christopher, Ian**; Haseltine Lake & Co., Imperial House, 15-19 Kingsway, London WC2B 6UD (GB).

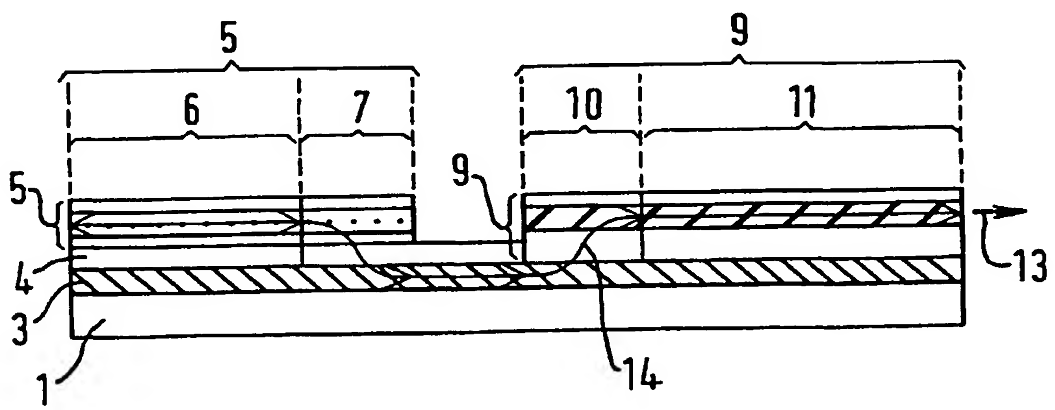
(81) Designated States *(national)*: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: INTEGRATED OPTICAL DEVICE WITH COUPLING WAVEGUIDE LAYER



(57) Abstract: An integrated optical device comprises first and second optical devices (5, 9) and an optical waveguide layer (3). Each optical device (5, 9) is arranged to be optically coupled with the waveguide layer (3). The optical devices to be coupled may be a distributed feedback semiconductor laser and an electro-absorption modulator, e.g.

WO 01/06286 A1

INTEGRATED OPTICAL DEVICE WITH COUPLING WAVEGUIDE LAYER

The present invention relates to optical devices, and in particular to integrated semiconductor optical devices.

BACKGROUND OF THE INVENTION

Conventional approaches for the integration onto single substrates of semiconductor opto-electronic devices with different band gap energy values, for example semiconductor lasers and external modulators, fall into three main categories.

In a so-called "butt-joint approach", one of the component structures (for example, a semiconductor laser) is grown epitaxially onto a semiconductor substrate. Unwanted growth areas are then removed from the surface of the substrate where another component structure (for example, a modulator) is to be formed. The second component structure is consequently grown in these areas. This approach suffers from several disadvantages; misalignment occurs between the optical wave guide layers of the different structures, and poor crystal quality and layer defamation can occur at the boundary between the two areas during the second growth step.

A second approach is known as the "selected area growth (SAG)" approach. In such a technique, the substrate is patterned before the devices are grown epitaxially on the substrate. All of the component structures are grown in a single process. The optical waveguide layers are therefore self-aligning. The necessary differences in material parameters, particularly the

band gap energies, are achieved by the fact that growth speed varies across a pattern substrate, which results in variations in parameters such as quantum well thickness. The main disadvantage of such a technique is that the achievable band gap difference is often limited. It is also difficult to optimise the two device structures independently because they must have the same layer structure and doping profile.

In a third technique, known as quantum well intermixing (QWI) the component quantum well (QW) structures are grown on a usual substrate in a single growth step. The band gap of a quantum well is changed by an intermixing process, which causes the QW to change material composition and geometric shape, resulting in band gap variation. The waveguide layer is again self-aligning. The main disadvantage with such a technique is that the achievable band gap differences are limited by the amount of achievable intermixing. The intermixing process is usually carried out at high temperatures and may therefore result in deterioration of the material quality. In addition, the intermixing process is sensitive to process environment and substrate surface conditions, which can result in low repeatability and control ability. It is also difficult to optimise the two device structures independently because they must have the same layer structure and doping profile.

SUMMARY OF THE PRESENT INVENTION

According to one aspect of the present invention, there is provided an integrated optical device comprising first and second optical devices and an optical waveguide layer, wherein each optical device is

arranged to be optically coupled with the waveguide layer.

According to a second aspect of the present invention, there is provided an integrated optical device comprising a substrate layer, a waveguide layer carried by the substrate layer, and a first optical device carried by the waveguide layer, wherein the first optical device is optically coupled with the waveguide layer.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates a first embodiment of the present invention;

Figure 2 illustrates a second embodiment of the present invention; and

Figure 3 illustrates a third embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As will be appreciated from Figure 1 of the accompanying drawings, embodiments of the present invention can overcome the disadvantages of the previously-considered integration techniques by providing an independent waveguide layer in the integrated device.

Figure 1 illustrates a first integrated optical device embodying the present invention. The device is formed on a substrate 1 and includes layers of material which form the device structures. The substrate carries a

waveguide layer 3 which is formed of a material which is able to carry optical signals, with low loss, such as a semiconductor material with wider bandgap, for example InP, GaAs or related compounds. The waveguide layer 3 is preferably enclosed by a cladding layer 4. On the cladding layer 4, or on the waveguide layer 3, individual optical devices 5 and 9 are provided. The first device 5 includes a device region 6 and a coupling region 7. The second device 9 includes a coupling region 10 and a device region 11. Each device is arranged such that it can couple optical signals with the waveguide layer 3. This optical coupling occurs because the devices are located in close proximity to the waveguide layer 3, and the coupling regions have propagation constants substantially equal to the waveguide layer 3. For example, a spacing of 1μm enables light to be coupled between the devices and the waveguide layer 3.

Each of the optical devices, however, is preferably provided with a coupling region in order to optimise the coupling between the device and the waveguide layer, as shown in Figure 1. The overall length of the device and its associated coupling region determines the mode in which optical signals are coupled between the device and the waveguide layer 3. When light is coupled into waveguide layer 3 from the devices, the lengths of the coupling regions are preferably chosen so that maximum optical power transfer occurs at the end of the devices. This serves to minimise optical loss and backscattering. When light in coupled from waveguide layer 3 into the devices, the lengths would be chosen either to facilitate maximum optical power transfer at the end of the coupling regions, or to facilitate a gradual optical power transfer along the device length. The former mode would gather most of the optical power at the entrance of the device regions, while the latter mode would give a more even optical power distribution along the device

length. Complete coupling can be achieved if the length of the coupling interface is equal to the beat length of the lowest order modes of the waveguide layer 3.

The coupling regions 7 and 10 are arranged so that strong optical coupling occurs between those regions and the waveguide layer 3. This can be achieved, as mentioned above, by making the propagation constants of the coupling regions substantially equal to that of the waveguide layer 3. Alternatively, the lateral waveguide shape of regions 7 and 10 could be tapered. The first device is arranged such that optical signals produced or processed by the device region 6 is coupled into the waveguide layer 3 of the integrated device through the coupling region 7. The optical signals coupled into the waveguide layer 3 are then coupled with the second device 9 by way of its coupling region 10. The coupling region 10 is coupled with the device region 11 for transferring a light optical signal to the device.

The integrated device is formed by growing the waveguide layer 3 (and optional protective layer 4) onto the substrate 1 and then by growing the individual devices 5 and 9 either in a single epitaxial growth operation, or in separate operations. The coupling regions of each device are formed integrally with the device regions, and so optical coupling between the two can be arranged to be strong.

Since each device 5 and 9 couples with the waveguide layer of the integrated device, for transfer of signals between the two devices, the devices need not be produced as part of the same fabrication step. The waveguide layer 3 provides an independent coupling path 14 for transfer of optical signals between the devices, and so the transfer is not dependent on achieving direct coupling between the devices.

Figure 2 illustrates a particular embodiment of the present invention, in which the first device is a

distributed feedback semiconductor laser (device region 6), and the second device is an electro-absorption modulator. Both devices use short lengths of coupling regions in order to optimise the coupling between the device and the waveguide layer 3. In the example shown in Figure 2, the waveguide layer 3 is passive and simply enables optical energy to travel between the two devices along optical path 14.

Another embodiment of the present invention is shown in Figure 3 in which a distributed feedback laser 6 couples to the waveguide layer 3 via a coupler 7. In the Figure 3 embodiment, a second device 15 is provided which again is an electro-absorption modulator. In the Figure 3 embodiment, however, the modulator 15 is provided by a modulator layer 16 to which a bias voltage can be applied. The waveguide layer 3 then provides part of the modulator itself.

It will therefore be appreciated that embodiments of the present invention are able to overcome the disadvantages associated with the prior art. For example, the Figure 3 embodiment is simple to manufacture, since only one epitaxial growth process is required, the modulator being manufactured by a simple metalling process.

Examples of optical devices that can be integrated on a substrate which carries a waveguide layer in accordance with the invention, are: a Fabry-Perot cavity semiconductor laser, a distributed feedback semiconductor laser, a distributed Bragg reflector semiconductor laser, an electro-absorption modulator, a Mach-Zehnder modulator, or an electro-optic modulator. Other optical components such as detectors or amplifiers are also suitable for use in embodiments of the invention. Naturally, the above lists of devices and components are not exhaustive, and other suitable devices and components can be used in integrated devices embodying the present invention.

CLAIMS

1. An integrated optical device comprising first and second optical devices and an optical waveguide layer, wherein each optical device is arranged to be optically coupled with the waveguide layer.

2. An integrated optical device comprising a substrate layer, a waveguide layer carried by the substrate layer, and a first optical device carried by the waveguide layer, wherein the first optical device is optically coupled with the waveguide layer.

3. A device as claimed in claim 2, comprising a second optical device carried by the waveguide layer and optically coupled with the waveguide layer.

4. A device as claimed in claim 2 or 3, wherein the first optical device is coupled with the waveguide layer by way of a coupling region of the first optical device.

5. A device as claimed in claim 2, 3 or 4, wherein the second optical device is coupled with the waveguide layer by way of a coupling region of the second optical device.

6. A device as claimed in any one of claims 2 to 5, wherein the first optical device is a distributed feedback semiconductor laser device.

7. A device as claimed in any one of claims 2 to 5, wherein the first optical device is a distributed Bragg reflector semiconductor laser device.

8. A device as claimed in any one of claims 2 to 5, wherein the first optical device is a Fabry-Perot cavity semiconductor laser.

9. A device as claimed in claim 3, or in any one of claims 4 to 8 when dependent upon claim 3, wherein the second optical device is an electro-absorption modulator.

10. A device as claimed in claim 3, or in any one of claims 4 to 8 when dependent upon claim 3, wherein the second optical device is a Mach-Zehnder modulator.

11. A device as claimed in claim 3, or in any one of claims 4 to 8 when dependent upon claim 3, wherein the second optical device is an electro-optic modulator.

12. A device as claimed in claim 3, or in any one of claims 4 to 8 when dependent upon claim 3, wherein the second optical device is a optical amplifier.

13. A device as claimed in claim 3, or in any one of claims 4 to 8 when dependent upon claim 3, wherein the second optical device is a optical detector.

14. A device as claimed in any one of claims 2 to 13, comprising further optical devices carried by and optically coupled with the waveguide layer.

15. A device as claimed in any one of the preceding claims, being a semiconductor device, wherein the or each optical device is provided by a layered structure.

16. A device as claimed in claim 15, wherein the or each optical device is formed by an epitaxial growth methos on the waveguide layer.

17. A device as claimed in any one of claims 2 to 16, wherein the waveguide layer comprises a layer of optically transmissive material, and a layer of protective material.

18. A device as claimed in claim 3, or in any one of claims 4 to 17 when dependent upon claim 3, wherein at least part of the second optical device is provided by part of the waveguide layer.

19. An integrated optical device substantially as hereinbefore described with reference to, and as shown in, the accompanying drawings.

1/1

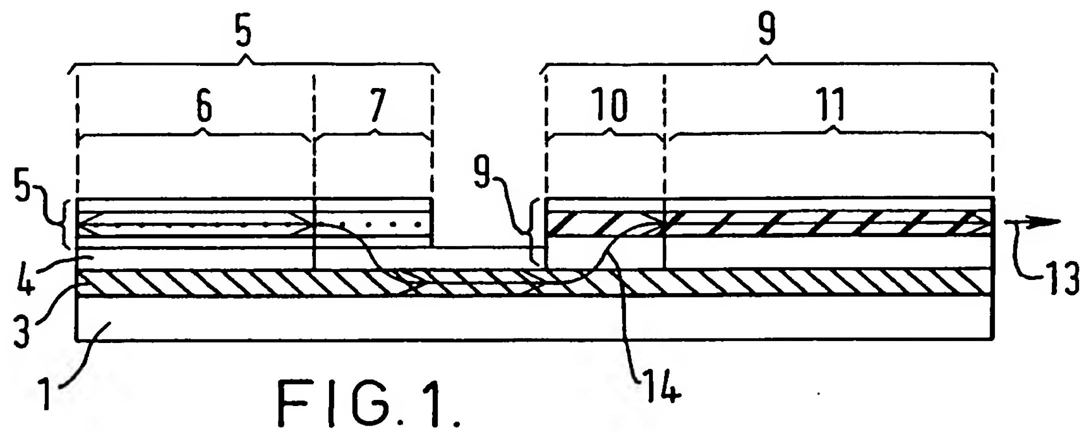


FIG. 1.

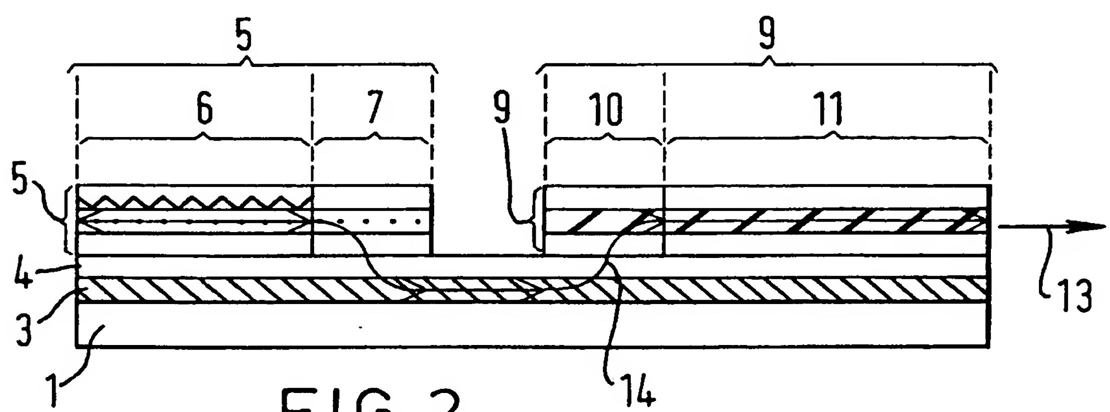


FIG. 2.

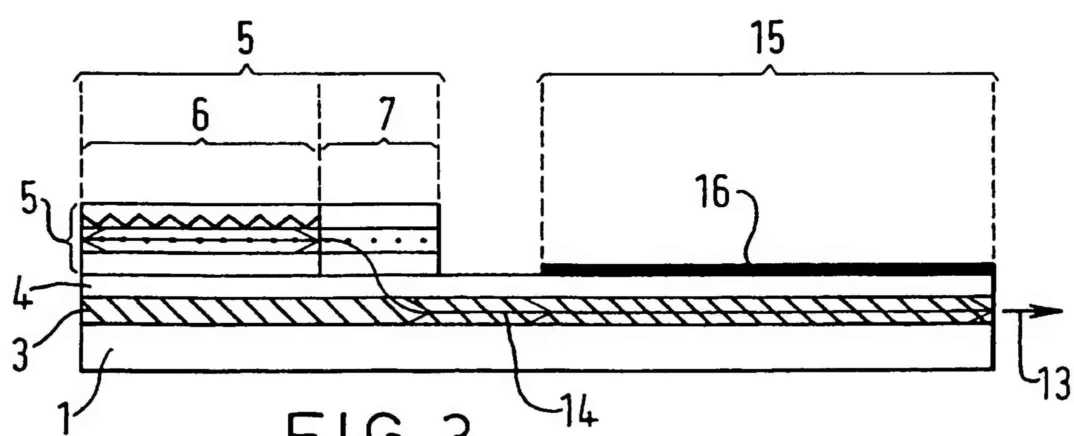


FIG. 3.

INTERNATIONAL SEARCH REPORT

In ational Application No
PCT/GB 00/02703

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, IBM-TDB, COMPENDEX, INSPEC, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	STUDENKOV P V ET AL: "MONOLITHIC INTEGRATION OF A QUANTUM-WELL LASER AND AN OPTICAL AMPLIFIER USING AN ASYMMETRIC TWIN-WAVEGUIDE STRUCTURE" IEEE PHOTONICS TECHNOLOGY LETTERS,US,IEEE INC. NEW YORK, vol. 10, no. 8, 1 August 1998 (1998-08-01), pages 1088-1090, XP000769865 ISSN: 1041-1135 abstract; figure 2 page 1090, right-hand column, paragraphs 2,3 ---	1-5,12, 15,16,19

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 October 2000	26/10/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Hylla, W

1

Form PCT/ISA/210 (second sheet) (July 1992)

In ational Application No
PCT/GB 00/02703

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	MERZ J L ET AL: "GaAs integrated optical circuits by wet chemical etching" IEEE JOURNAL OF QUANTUM ELECTRONICS, FEB. 1979, USA, vol. QE-15, no. 2, pages 72-82, XP002149407 ISSN: 0018-9197 page 72, right-hand column, paragraph 2 -page 73, left-hand column, paragraph 2; figure 1 ---	1-5,13, 15,16,19
X	EP 0 464 869 A (SIEMENS AG) 8 January 1992 (1992-01-08) column 4, line 20 -column 5, line 25; figures 1,2 ---	1-5, 13-17,19
A	SHAMS M K ET AL: "Monolithic integration of GaAs-(GaAl)As light modulators and distributed-Bragg-reflector lasers" APPLIED PHYSICS LETTERS, 1 MARCH 1978, USA, vol. 32, no. 5, pages 314-316, XP002149408 ISSN: 0003-6951 page 314, left-hand column, paragraph 1; figure 1 page 314, right-hand column, paragraph 2 ---	1-7,9, 11,15,18
A	US 5 022 038 A (BRADLEY ERIC M) 4 June 1991 (1991-06-04) abstract; figures 1-3 column 3, line 17 - line 22 ---	8
A	US 5 524 076 A (ROLLAND CLAUDE ET AL) 4 June 1996 (1996-06-04) abstract; figures 1,1A -----	10

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/02703

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0464869 A	08-01-1992	AT 88014 T	15-04-1993
		DE 3587249 A	13-05-1993
		EP 0187979 A	23-07-1986
		JP 61163303 A	24-07-1986
		US 4747649 A	31-05-1988
US 5022038 A	04-06-1991	NONE	
US 5524076 A	04-06-1996	NONE	